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(71)(72) Applicant and Inventor: HABER, Michael, B. [AU/AU]; 7 Boonah Street, Wentworthville, NSW 2145 (AU).

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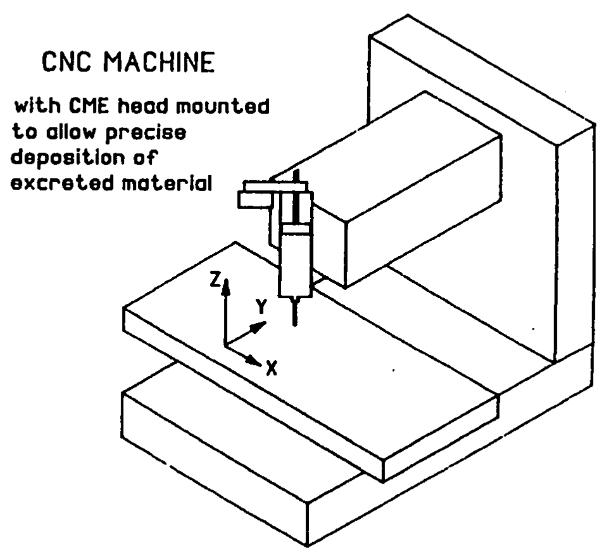
(54) Title: COMPUTERISED MACRO-ASSEMBLY MANUFACTURE

(57) Abstract

The present invention relates to a manufacturing method where items are made similarly the way a variety of insects build up their habitats. That is by assembly of minute particles or threads of mater with a bonding ingredient in some predetermined orderly fashion so that an object of required shape is created. This is accomplished by a robot or a numerical controlled machine which controls position of a specially designed head from which special material is excreted which quickly solidifies and therefore retains programmed shape.



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COMPUTERISED MACRO-ASSEMBLY MANUFACTURE

The present invention relates to a manufacturing method where items are made similarly the way a variety of insects build up their habitats. That is by assembly of minute particles or threads of matter with a bonding ingredient in some predetermined orderly fashion so that an object of required shape is created. This is accomplished by a robot or a numerical controlled machine which controls position of a specially designed head from which special material is excreted which quickly solidifies and therefore retains programmed shape.

BACKGROUND ART

3D modelling with liquids which polymerize on illumination with focused laser beam light is in existence. Here the beam, the position of which in X-Y co-ordinates is computer controlled, is focused onto the surface of the fluid. Illuminated part at focus of the beam solidifies and once the full layer is completed, it is lowered, thus rising the level of fluid above it, so that the next layer could be formed.

OBJECT OF THE INVENTION

It is an object of the present invention to provide an apparatus and method of manufacturing objects of any shape, size or surface texture.

DISCLOSURE OF THE INVENTION

Machines which allow this kind of manufacture of matter consists generally of either:

a) robot arms with at least 5 axis of freedom of movement,

b) light framed numerically controlled machine which would have a head or a number of heads which would have 3 to 5 axis of freedom of movement. Each head or robot arm have specially designed head allowing excretion or projection of particles or fibres of matter on a small to microscopic scale in such a controlled fashion so as to allow buildup of the material and retention of shape. Material needs to solidify sufficiently straight after deposition (pre-cure) and then full curing could be induced consequently. Also after basic shape is created additional layers could be applied in similar fashion or by any other means, like laminating thin layers consisting of carbon fibres & epoxy.

Thus by properly designed programs which would control movement of the head and the manner in which matter is excreted, it would be possible to create objects of any shape, size or surface texture. For example utilising thin shell structure design with variable wall thickness it would be possible to create objects with superior strength/weight.

Of a particular interest is honeycomb structure created by bees, for its excellent strength to weight properties. This method of manufacture would provide means of creating any shape with the variable honeycomb wall structures.

BRIEF DESCRIPTIONS OF THE DRAWINGS

Some embodiments of the present invention will be described with reference to the drawings in which:

Fig. 1(a) is a perspective view of a computer numerically controlled (CNC) machine with a ceramic material excretion (CME) head mounted thereon,

Fig. 1(b) is a detailed side view of the CME head as seen in Fig. 1(b),

Fig. 2 is a cross sectional view of a thermoplastic material excretion head for use with the machine as illustrated in Fig. 1(a),

Fig. 3(a) is a perspective view of a 3D shaped object,

Fig. 3(b) is a bottom view of the object of Fig. 3(a),

Fig. 3(c) is a top view of the object of Fig. 3(b),

Fig. 3(d) is a detailed view of a typical basic cell,

Fig. 4(a) is an example of an aircraft wing using the manufacturing method of the present invention,

Fig. 4(b) is an example of a mast of a yacht using the manufacturing method of the present invention,

Page 8 is a sample of numerical data; and

Page 9 is a sample algorithm for a simple cell macrostructure.

BEST MODE OF CARRYING OUT THE INVENTION

The present invention of Computerised Macro-Assembly Manufacture (CM-AM) is not the robot or NE machine alone which allows computer programmed movements, but is this unique usage of CNC machines or robots in combination with:

a) special heads designed for material deposition

b) a particular type of material with suitable properties,

c) computer software which allows various methods of building-up walls of objects by having defined cell macrostructure.

CM-AM was first tried with type of head where material deposited was clay. Schematic of this is shown in Fig. 1 and actual example of shape created is shown in Fig. 3. Its wall macrostructure is shown and this can be represented by a simple algorithm as shown in Page 9. Next trial was with thermoplastic material as made by the container as shown

in Fig. 2. There are many types of materials with suitable designed heads possible for this type of manufacture, some of which are listed below with brief description of applications.

SPECIFIC DESCRIPTION

a) WME Head (Wax Material Excretion) for CM-AM
b) CME Head (Ceramic Material Excretion) for CM-AM
c) PME Head (Polymerising Material Excretion) for CM-AM
d) EME head (Epoxy Material Excretion) for CM-AM
e) MME Head (Metal Material Excretion) for CM-AM
f) TME Head (Thermoplastic material Excretion) for CM-AM

Brief description with applications of each is given below.

WME Head for CM-AM

Wax material is the first material when one looks at analogies of this method of manufacture in nature. Bees are making their beehives in this fashion.

This material has also wide application in engineering, for example in modeling of 3D components, but particularly in manufacture of strong metal components by method of "investment casting".

In this method a model of the component is made out of wax, by standard machining methods, then this component is covered with slurry of ceramic material which eventually dries into a high temperature resisting shell. After melting away the wax core, a cavity remains into which molten metal is cast to a required shape. Shell is consequently broken away.

Because of the low melting temperature of wax, it is relatively simple method of designing a head for excreting wax, under pressure, with controlled flow, and with such ambient conditions at the entrance nozzle so that the material solidifies soon after it leaves the nozzle. Variations in design of the head can be due to a particular application, from simple 3 axis head for making simple thin shell 3D models to 5 or more axis head where characteristics like surface texture or wall thickness could be controlled as well.

With CM-AM method of manufacturing wax components, more exotic shapes can be designed and made for both 3D modelling applications as well as for manufacturing components by the "investment casting" methods.

CME head for CM-AM

Again nature provided us with an example - termite mounts. Clay was first material to try CM-AM. Motorised syringe was mounted on the

CNC machine as illustrated in Fig. 1. This was filled with clay of sufficient plasicity. The machine was programmed to produce shape as shown in Fig. 3. There are many software packages to simplify this kind of programming, so called CAM (Computer Aided Manufacturer). The particular CAM used in this case is Smartcam Advanced 3D. Sample (start and end) of the code generated is also shown in Page 8. Simple algorithm was also created to allow automatic generation of the cell structure as shown in Fig. 3. Essential aspects of this algorithm are shown in Page 9.

With some infringements the type of head with appropriate material would allow making directly for example:

i) hollow ceramic shells directly for "investment casting" without having to make wax model,

ii) making exotic shapes from hi-tech materials to withstand for example high temperatures or having specific electric or dielectric properties.

Proper design of the head allows excretion of material, at controlled rate, which is suspended in appropriate fluid. On excretion partial curing is assisted by focused light or heat, evaporating quickly suspension fluid. Full curing is achieved in high temperature baking oven where also full bonding of particles is achieved.

Advantages of CM-AM with this materials is the possibility of exotic shapes out of refractory, high temperature materials, without need for expensive machining of hard materials. Full utilisation of hi-tech, expensive materials without any wastage. Low tooling-up cost and fast flexible designs.

PME Head for CM-AM

3D modelling with liquids which polymerize on illumination with focused laser beam light is in existence. Here the beam, the position of which in X-Y co-ordinates is computer controlled, is focused onto the surface of the fluid. Illuminated part at focus of the beam solidifies and once the full layer is completed, it is lowered, thus rising the level of fluid above it, so that the next layer could be formed.

The present invention differs completely, in that material being excreted from a nozzle of a special head and is illuminated by the focussed laser beam as it is leaving the nozzle, thus causing polymerisation and therefore solidification right after it was deposited onto already existing structure.

The major advantage with our method is the possibility of more

complex shapes, for deposited layers do not have to be in horizontal planes (given by the surface of fluid in the existing method), but could be gradually assuming any orientation because only minute portion at the end of the excretion nozzle is in fluid form.

Another important advantage is that in the method, filing and reinforcing materials could be added to improve the physical properties of finished components. For example glass or carbon fibres or particles. Thus this could be used not only for 3D modelling, but for making finished products with desired strength variation of this head is where continuous fibre of, for example, glass or carbon is fed together with polymerising material which bonds fibres together. The process would become similar to weaving basket or cloth, or simply laying layer by layer first in one direction, and then if necessary in other direction. In this fashion it is possible to create strong, thin shell structures, or of more complex wall (like honeycomb) structures.

EME Head for CM-AM

Epoxies play an important role as bonding materials in many composite or laminated applications. Heads which allows using epoxies together with fillers in particulate form or as continuous fibres would be similar to heads used with polymerising materials.

Epoxy is mixed with catalyst prior to leaving the nozzle, and is further assisted in fast pre-cure by appropriate ambient conditions and further accelerated by, for example focused laser beam. full curing is achieved in given time. This can be accelerated by post-cure low temperature baking.

Current use of these materials in aero-space industry can be further expanded by the possibility of more exotic shapes, lower tooling costs (traditional methods call for male or female molds) and greater flexibility of designs.

Variant of this design is a composite head where two different types of materials are being deposited simultaneously. For example head creates tube with thin wall, middle of which is filled with low specific gravity material core. This tube is deposited layer by layer, with variable width or at an angle.

MME Head for CM-AM

Background Art - Robots are being used to weld up or resurface worn-out surfaces on metal components. Our proposal differs completely in that complex call macrostructure of walls is created, in any

direction, rather than applying one continuous layer onto existing surface.

Metal deposition with CM-AM is proposed to be used in two basic variations:

a) Molten metal is deposited or sprayed or sputtered.

b) Solid wire is fed from the head and at the some time it is welded to already existing structure, this also softens the wire allowing it to assume required shape more readily.

Second or more layers can be deposited consequently at different angles to give the structure required strength in different directions, or a process similar to basket weaving could be used, where more intricate, multiple head design would be required.

Composite head or a number of heads can be also used where a layer of metal is covered with another layer of different material, say of epoxy. This would give the structure for example imperviousness, protecting the core metal material from external elements.

Of course standard methods of painting or laminating these structures can be used as well. However, this can be applied only on external surfaces, but with our CM-AM method this coating can be applied also on internal surfaces, which consequently may not be accessible.

TME Head for CM-AM

Thermoplastic material is the first material which we tried to produce practical and strong components by this method of manufacture. (Clay samples on page 3 above served purpose but were too brittle to be of any practical use.)

Because of the relatively low melting temperature of thermoplastic materials, (for example Polypropylene at 200-300°C) it is relatively simple method of designing head for excreting this, under pressure, with controlled flow, and with such ambient conditions at the entrance nozzle so that the material solidifies soon after it leaves the nozzle. Fig. 2 shows typical head design. Variations in design of the head can be due to a particular application, from simple 3 axis head for making simple thin shell 3D models with simple 3 axis head for making simple thin shell 3D models with simple macrostructure to 5 or more axis head where head can be aligned with direction and inclination of the surface, and this way for example preheating of existing surface, each wall of individual cells from which walls are made.

With CM-AM method of manufacturing thermoplastic components, for

example prototypes of exotic shapes can be made without making expensive tooling for injection moulding. In many applications where small quantities and very exotic shapes are required this could be sufficient, and if required components could be finished by applying lamination on its external surfaces.

INDUSTRIAL APPLICABILITY

Obvious advantages over the conventional methods of manufacture are:

Greater freedom of shape designs.

Possibility of non-homogenous properties of the design, building-up the strength where it is required without affecting the external shape, by changing macrostructure of the walls of the design.

Relatively inexpensive machine due to its light weight construction. Forces encountered would be much less than those usually encountered with the conventional Computer Numerically Controlled (CNC) machine tools where large amounts of material have to be removed in given time.

Low cost of tooling for particular objects to compare to a cost of, for example tooling for plastic moulding. Only computer program would be needed to represent an item and computing power with time is getting less expensive.

Simple and inexpensive way of modelling 3D designs by building thin shell structure of the external shape only.

In principle it implies greater utilisation of materials, by using only as much as required in building-up of the object, rather than starting with more material and then removing the unwanted amount which is often wasted. Also material removal is often not to optimise material usage but to only obtain required external shape.

Another advantage of such created structures is that mathematical models of these can be readily represented in software programs like Finite Elements Analysis, giving means of fully predicting its mechanical properties.

A disadvantage is the relatively slow method of manufacture therefore this method is envisage to be used either:

a) for prototyping of designs before expensive tooling for plastic mould is contemplated,

b) in small to medium production runs,

c) in high-tech applications where superior strength to weight or exotic shapes are required.

Speed of manufacture can be substantially improved with multiple head machine design, in cases where additional complexity would be justified by increased rates of production.

This method of manufacture would be ideal for manufacturing out in space, because of special requirements and also because of the special conditions of zero gravity and vacuum.

a) One universal lightweight machine could be used to manufacture any object.

b) 100% utilisation of available resources of raw materials.

c) Ability to create sophisticated shapes with ultimate strength/ weight ratio, specially in zero gravity where less emphasis could be placed on fast "pre-curing".

d) Availability of sophisticated computing power to design these objects and to control the machine making them.

e) High vacuum environment could also be of advantage for in many materials entrapped gas bubbles reduce strength. Also many welding processes benefit from inert ambient conditions. Various particles could be deposited where high vacuum is a must.

<u>SAMPLE OF NUMERICAL DATA</u>

1	%00050	(start of program
2	G40 G90 G17	(absolute coordinates
3	M10 G00 X34.1 Y-4.0 Z1.0	(fast move, no material
4	M12 G01 X27.7 Y-0.5 F0600	(mat. on at 600mm/min
5	X26.9 Y-6.6	(next moves, all in
6	X34.0 Y-5.0	(straight lines......
7	X31.9 Y-12.7	
8	X26.6 Y-7.7	
9	X24.2 Y-13.4	
.		
.		
2337	X14.1 Y6.4	
2338	X18.4 Y8.8	
2339	X18.5 Y3.4	
2340	X14.1 Y5.7	
2341	Y0.4	
2342	X18.5 Y2.7	(last moves with
2343	Y-2.7	(material on
2344	M10 G00 Z20.0	(material off, move up
2345	M30	(end of program.

SAMPLE ALGORITH FOR A SIMPLE CELL MACROSTRUCTURE

1) External shape is broken into facets, length of which are given by the required smoothness of the surface Fig. 3(a)

2) Each facet represents external side of a cell as shown in Fig. 3(b) or Fig. 3(c). On each of these facets is constructed a triangle, with the two other sides of equal length, and where the height of this triangle represents the wall thickness. Corresponding internal cells are created by joining aspects of these triangles, length of these is therefore related to curvature of the shape.

3) This type of cell design allows efficient deposition of bead of material without interuption as is demonstrated in Fig. 3(d). Gaps at the aspects of each triangle are given by thickness of bead less amount of overlap required for good, strong bonding.

4) There would be some restrictions around cornerners with this simple algorithm, as shown on top of the shape (Fig. 3(c)), where internal length is at its minimum. Some variations to the algorithm at corners would overcome this .

5) Walls can be build-up by having the same structure applied a number of times, if necessary of finer cell size then external smoothness of walls would call for.

6) For simplicity we have made the number of facets in each vertically deposited layer the same. This would ensure constant number of cells in the wall structure. As each layer is deposited, elements of new cell corresponds to those of previous layer, with slight displacement allowing for change in shape. More complex shapes would require starting of new cell at some other locations, there are many variations to this basic algorithm.

7) Many other algorithms can be generated, for example hexagonal shapes which would be more efficient for filling larger volumes. Example of this is shown in Fig. 4(b).

CLAIMS

1. A system consisting of an apparatus with a head which has a storage of material and having a nozzle from which the material is excreted or ejected, where this head is mounted on mechanism allowing it to move in at least 3 axis X, Y, Z under numerical control and thus being able to deposit this material at different locations where this material is retained due to its property of solidificatioin and adhesion or welding-like process, controlled amounts at a time and layer by layer in an intricate pattern to create walls consisting macroscopically of cells of various designs so as to create object of any shape as designed previously with assistance of computers and suitable software.

2. A system as claimed in claim 1 where robot like apparatus is used allowing at least 5 axis of movement, X, Y, Z, as well as head rotation and its inclination so as to be aligned tangentially with already created parts and therefore be able to create more complex shapes where material is deposited at different angle at different locations and due to this more flexible head it is capable of having additional features which assist the material to adhere to previously deposited portions by means of welding or soldering or application of adhesive material and also being capable of having means of assisting curing or solidification of just deposited material by such means like focused laser beam or jet of hot gas and therefore being able to create objects with more complex cells or walls.

3. System as claimed in claim 1 and 2 wherein material for deposition is not stored in the head but is stored somewhere else and is transferred to the depositing head either through flexible pipework or taken to it in wire form.

4. System as claimed in claims 1-3 wherein apparatus is setup in space free of gravity and thus providing this apparatus with capability of being able to create more complex shapes and out of materials which are not dependent to such an extent on having sufficient strength straight after deposition so as to retain already created shape, or having need for inert atmosphere which prevents oxidation, thus allowing not only material excretion but also a wider range of particles projection, welding process, metal deposition or sputtering.

5. A system as claimed in any of the above claims wherein instead of one head there are multiple of heads used to increase speed of object creation or creating even more complex shapes where these heads are under

special control unit so as to prevent collision of these heads while efficiently building up a shape of the object.

6. A method of creating an object of any shape by designing it with assistance of a special computer software created not only for the purpose of efficiently designing its external shape, but for the purpose of simplifying or fully automating designing of the walls macrostructure from which walls of the object consist and then generating necessary numerical data which is sent to the apparatus as claimed in any of the above to create real physical objects.

7. A method as claimed in claim 6 wherein design computer takes care of external shape and the macroscopic structure of its walls is taken care of in a special controller as a subroutine within this controlling capabilities of the apparatus itself.

8. A method as claimed in claim 6 above wherein design computer takes care of external shape and the macroscopic structure of its walls is taken care of by special characteristics of the material which is deposited in a form of either small bubbles or in tubular form from which walls of an object are created.

9. Apparatus comprising the head of a system as claimed in any of claims 1-5 where thermoplastic material is maintained in liquid form and is excreted or ejected onto already formed shape and where it adheres and then fully solidifies due to a drop in temperature.

10. Apparatus comprising the head of a system as claimed in any of claims 1-5 where material particles are suspended in a liquid to form a paste and is excreted or ejected onto already formed shape and where it adheres and solidifies due to evaporation of the suspension liquid, and where this process can be accelerated by various means like a jet of hot gas, focussed beam of heat or light and further curing of the finished product can achieve the final required properties.

11. Apparatus comprising the head of a system as claimed in any of claims 1-5 where material is in liquid form and is excreted or ejected onto already formed shape and where it adheres and solidifies due to polymerisation process affected by focussed laser beam.

12. Apparatus comprising the head of a system as claimed in any of claims 1-5 where material is two part epoxy like material and prior to its being excreted or ejected it is mixed together and then deposited onto already formed shape and where this process can be accelerated by various means like jet of hot gas, focussed beam of heat or light and

further curing of the finished product achieves the final required properties.

13. Apparatus comprising the head of a system as claimed in any of claims 1-5 where material is in a small rod or wire form of any length and is deposited or laid onto already formed shape and is brought to plastic state in order to take its place and adhere to or welded to at its location by various means like a jet of hot gas, focussed beam of heat or light or flame or with assistance of an electric arc or being bombarded with a beam of particles.

14. Apparatus comprising the head of a system as claimed in any of claims 1-5 where material particles, which may or may not be electrically charged, are ejected at high velocity under suitable ambient conditions and are embedded into already created parts with or without the assistance of electric or magnetic fields.

15. Apparatus comprising the head of a system as claimed in any of claims 1-5 where material excreted is a composite consisting on solidification of a solid outside and lower density material inside, where these can be deposited in the form of either small bubbles or in the form of continuous tubular shapes.

16. Apparatus comprising the head of a system as claimed in any of claims 1-5 where material excreted is a composite consisting of a paste or liquid like material excreted is a composite consisting of a paste or liquid like material which is filled with particles, fibres or continuous fibres at its core where paste or liquid provides adhesion and filling materials or its core fiber provided additional strength.

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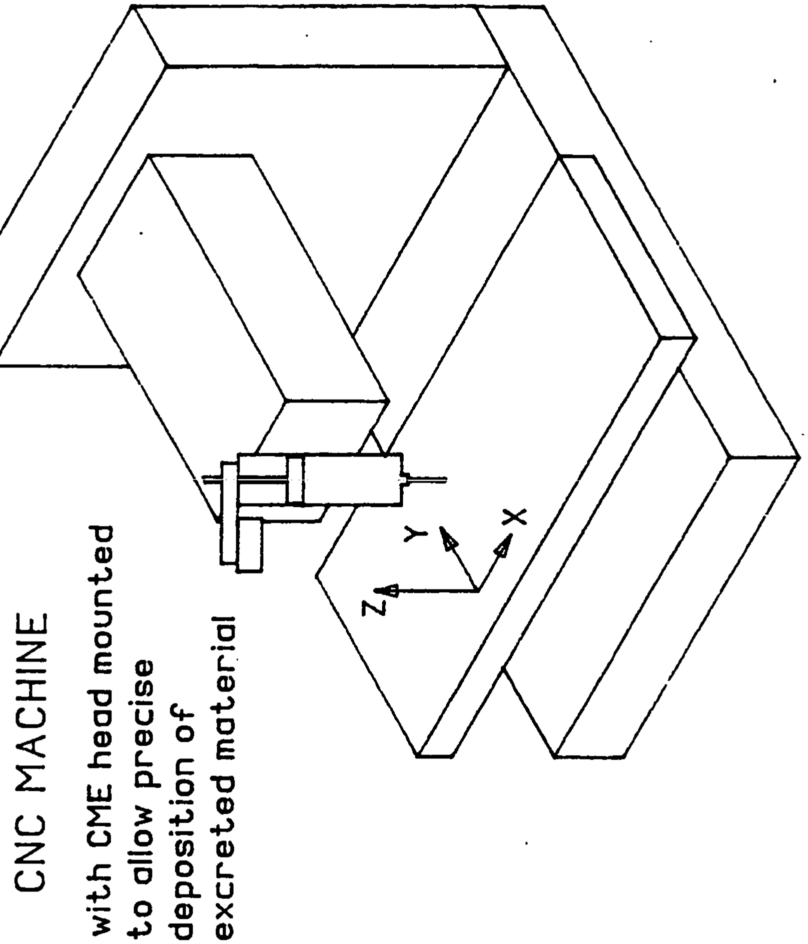


Fig. 1(a)

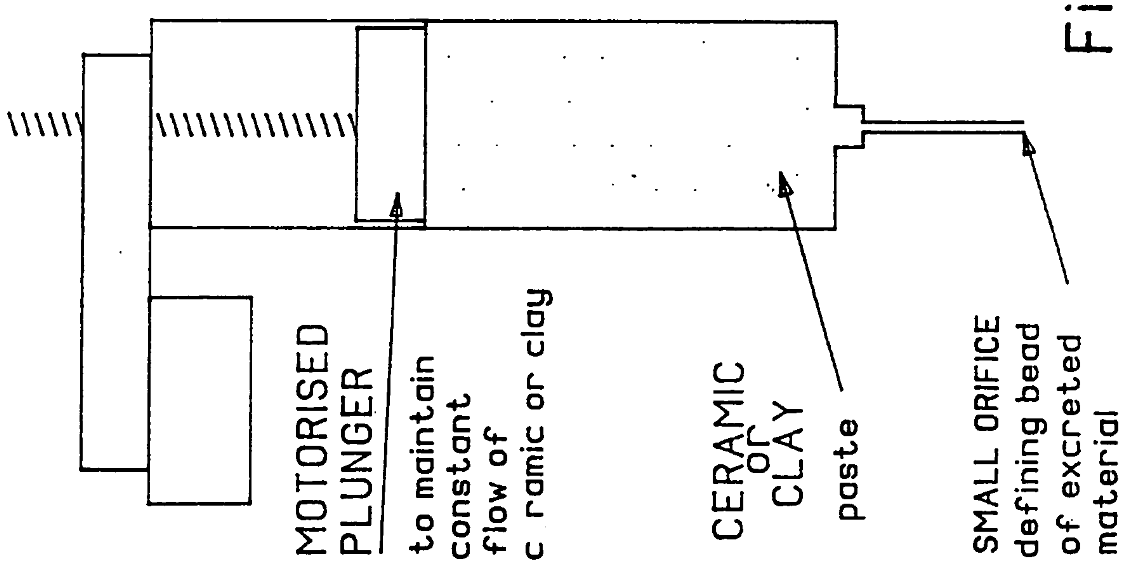


Fig. 1(b)

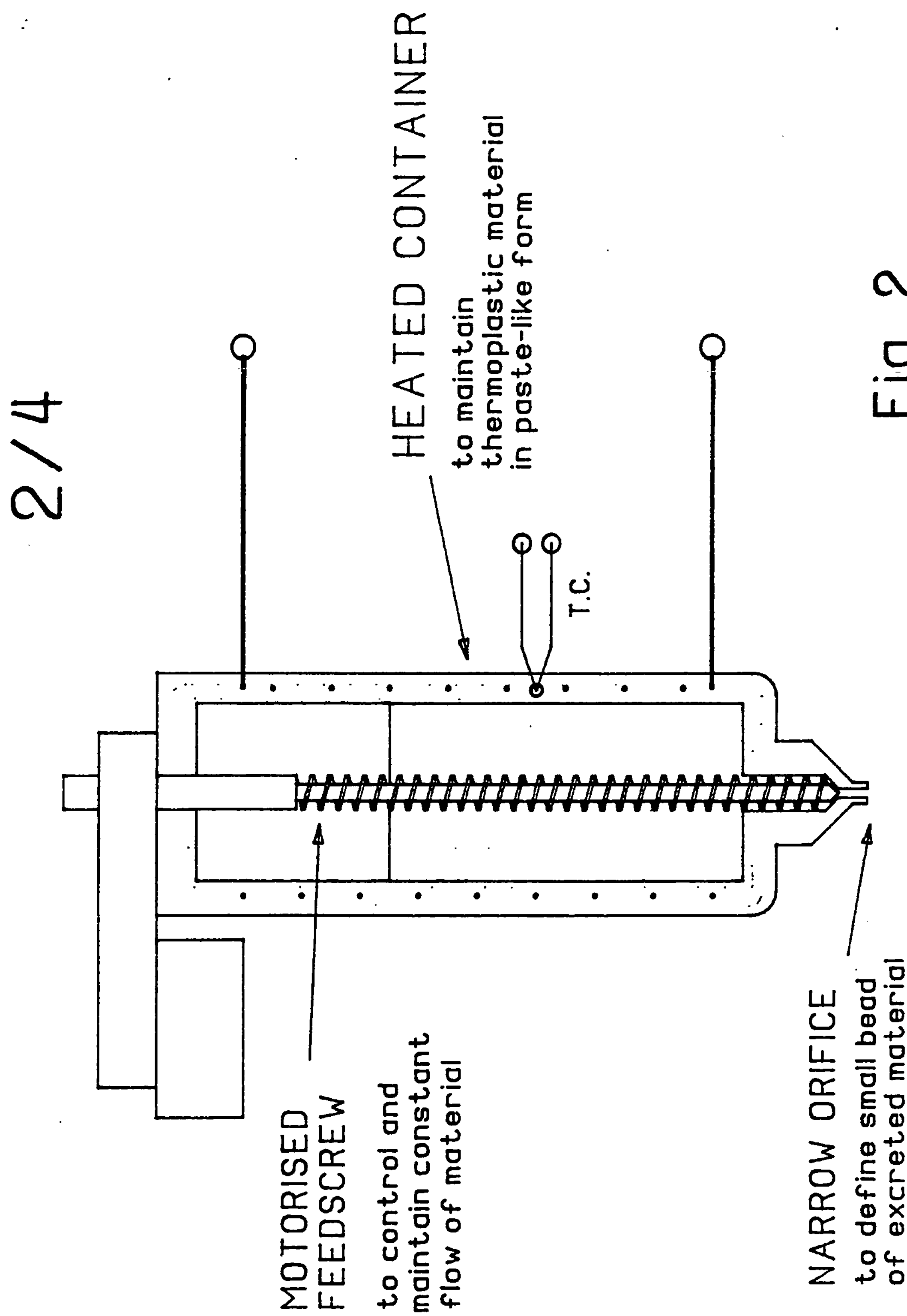

2/4
HEATED CONTAINER
to maintain
thermoplastic material
in paste-like form
T.C.
MOTORISED
FEEDSCREW
to control and
maintain constant
flow of material
NARROW ORIFICE
to define small bead
of excreted material

Fig. 2

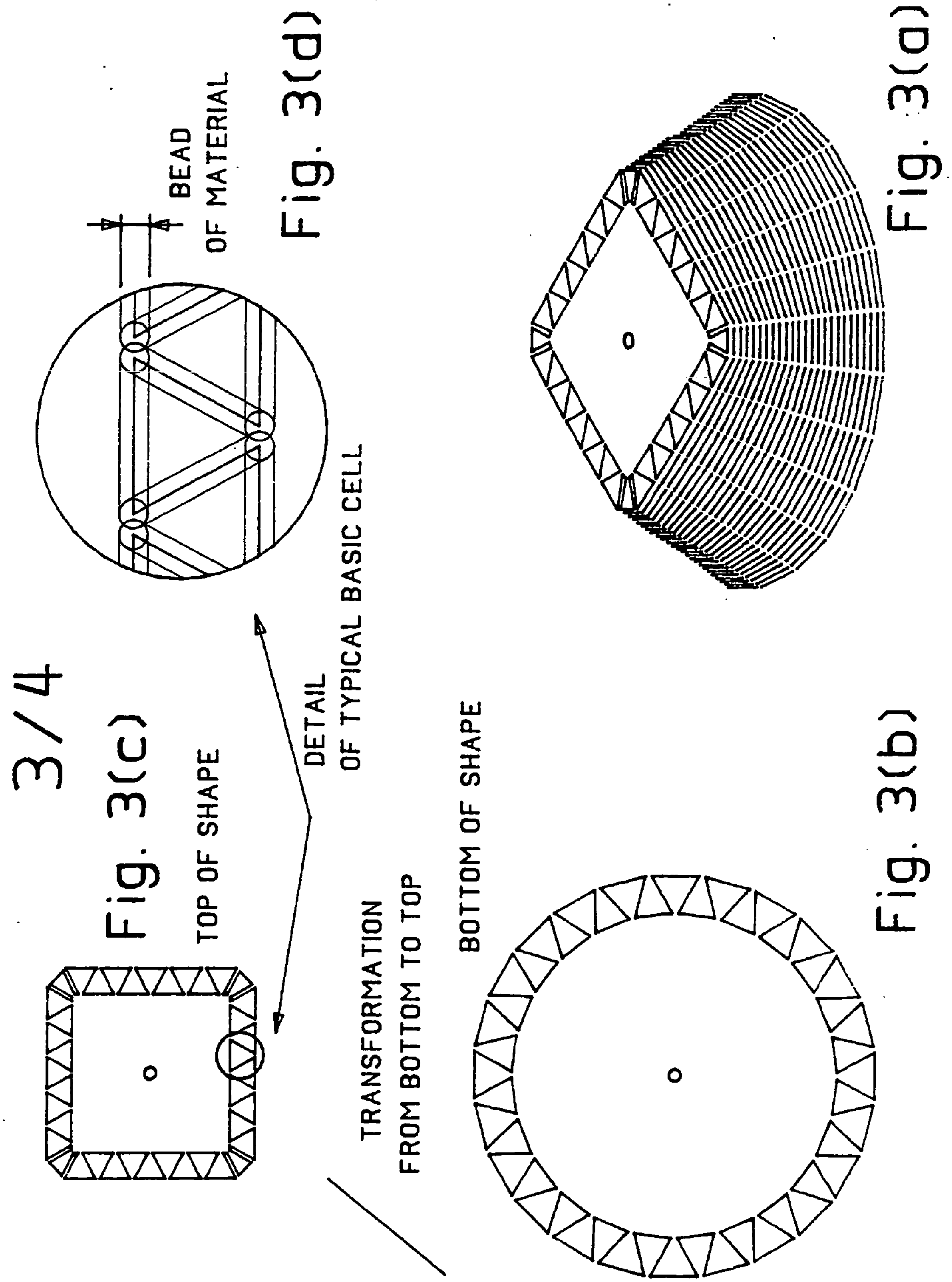
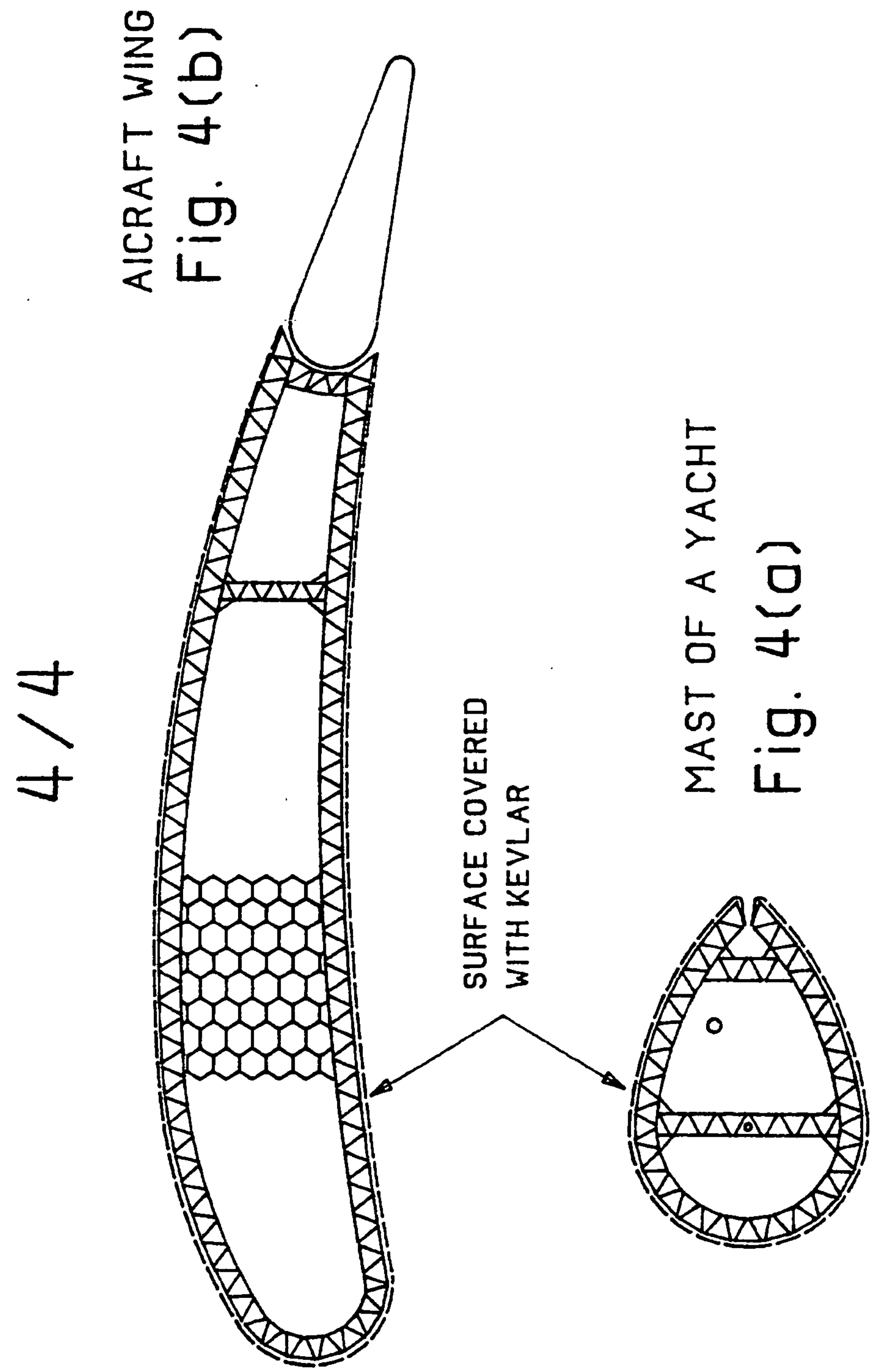


Fig. 3(a)

Fig. 3(b)

Fig. 3(c)

Fig. 3(d)


4 / 4
AICRAFT WING
Fig. 4(b)
SURFACE COVERED
WITH KEVLAR
MAST OF A YACHT
Fig. 4(a)

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent classification (IPC) or to both National Classification and IPC

Int. Cl.[5] B29C 67/02, G05B 19/18, B28B 1/29, B22D 23/00, 25/02

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	B29C 67/02, G05B 19/18
IPC^3	B29C 23/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category*	Citation of Document, [11] with indication, where appropriate of the relevant passages [12]	Relevant to Claim No [13]
A	Patents Abstracts of Japan, M 284, page 14, JP,A, 58-211413 [KOGYO GIJUTSUIN (JAPAN)] 8 December 1983 (08.12.83)	(1-16)
A	Patents Abstracts of Japan, P 210, page 163, JP,A, 58-70313 (DAISAN GIKEN KOGYO K.K.) 26 April 1983 (26.04.83)	(1-16)
A	Derwent Abstract Accession No. 00007k/01, class X24, BE,A, 893526 (AGIP NUCLEARE SPA) 15 December 1982 (15.12.82)	(1-16)

* Special categories of cited documents : [10]

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"T" Later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
25 June 1992 (25.06.92)	3 July 1992 (03.07.92)
International Searching Authority	Signature of Authorized Officer
AUSTRALIAN PATENT OFFICE	J.P. ELIJAH

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